PATENT SPECIFICATION

(11) 1 215 842

DRAWINGS ATTACHED

1 215 842

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(54) REPRODUCTION OBJECTIVE

(71) We, COMMISSARIAT A L'ENERGIE ATOMIQUE, an organization created in France by Ordinance no. 45-2563 of October 18th, 1945, 29 rue de la Fédération, 75 Paris (France), do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to reproduction objectives, that is to say objectives intended for the reproduction for example of plans, documents or drawings. The invention is more particularly, but not exclusively, concerned with objectives of this type which have a given magnification (lower than 1) and which are intended to product reduced images with excellent definition, in particular for making printed circuits of small dimensions of microcircuits of the integrated circuit type and microfilms of substandard format (smaller than 35 mill meters (mm)).

An object of the present invention is to provide reproduction objectives having good definition, as a result of the elimination of the various aberrations, and having a large aperture.

According to the present invention, there is provided an objective for high definition reproduction, of larger aperture and having a given magnification, the objective consisting of the following groups (taken from the object to the image) of lenses: a first group formed by a first single lens of high refractive index, the focal length of which single lens is of the order of ten times the focal length of the objective, said single lens determining the magnification (lower than 1) of the reproduction; a second focal group, having a focal length at least five times greater than that of said first lens for progressively correcting aberrations introduced by the lens or lenses of the third group; a third group, formed by a second single lens or two lenses, which determines the power of the objective, the focal length of this group being of the same order of size as the focal length of the objective e.g. between 15 mm and 50 mm and the refractive index of the or each lens of the group being greater than 1.75; a fourth group formed by a single divergent lens, having a refractive index of less than 1.55, for correcting the curvature of the field and the Petzval curvature, the power of the single divergent lens being determined by the Petzval correction to be effected.

This invention is particularly applicable to objectives having a magnification of the order of 1/10 and an aperture n sine u of the order of 0.50 for the manufacture of microcircuits.

For a better understanding of the invention reference will now be made, by way of example, to the accompanying drawing which is an axial sectional view of the lenses of an objective constructed according to the present invention, showing the paths of a certain number of luminous rays (shown in solid lines) at a greater or lesser distance from the optical axis (shown in a dot-dash line).

The objective shown in the drawing has a very large aperture (n sine u = 0.50), a given magnification of 1/10 and an average definition, in a field of 3.5 mm diameter, of 1500 lines/mm for the g line of mercury of wave length 4358 angstroms). This objective comprises four groups I, II, III, IV of lenses of common optical axis, XX, namely, from the object plane (not shown) to the image plane Pi:

First of all, a first group I formed by a single lens A (limited by the surfaces 1 and 2) of low power (i.e. focal length being 8.5 mm for an object situated at 85 mm from the front surface 1 of the lens of high refractive index (1.8 for the d line of helium of wave length 5876 angstroms, all the refractive indexes being indicated for this line) so that this lens introduces only the minimum of aberrations. The lens A, which determines the magnification (equal to 1/10 of the reproduction, permits the use of the objective groups II, III and IV which follows it on the direct side of travel of the

luminous rays) to operate as if it were operating for an object situated at infinity, due to the fact that the object to be reproduced is substantially in its object focal plane. The magnification of the objective can thus be changed by substituting for the lens A, which is thus preferably removable, an analogous lens having a different focal length.

The objective comprises next to a second group II of lenses which is a practically afocal group, that is to say without power, formed advantageously by seven lenses B, C, D, E, F, G, H (limited by the surfaces 3 to 15 as shown) intended to correct progressively the aberrations introduced by the lens J of the third group III which is a convergent group. The high number (of the order of seven) of lenses of the second group permits progressive correction to be made resulting in an objective quality, which would not be possible if a corrective group were used having a smaller number of lenses operating at the limit of their possibilities for achieving large corrections. The lenses of the second group correct in particular the anti-nodes of spherical aberration and of curvature of the field, the variations the 2/3 field. These lenses can be grouped of coma between the edge of the field and in four successive sub-groups II*a*, II*b*, II*c*, II*d*, namely:

— a first sub-group II*a* comprising two lenses B and C of rather high refractive index (1:72) intended to correct in part the spherical aberration and the curvature of the field; these lenses have focal lengths of 98 and 78 mm respectively; each of these lenses works at an average aperture of F/3 about; in variations, the lenses B and C can be grouped in a single lens, thus decreasing the aperture of the overall objective, or on the contrary, a third lens can be added to the lenses B and C (the three-lens sub-group having the same power as the original (two-lens sub-group II*a*), which would permit the aperture of the objective to be increased;

— a second sub-group II*b* formed by a single bi concave lens D, hence divergent, of focal length — 78.1 mm which permits a correction of the spherical aberration and of the external coma while improving the Petzval curvature;

— a third sub-group II*c* of very low power (focal length — 2,219.7 mm) having two lenses E and F cemented together; the difference between the Abbe numbers (60 and 28) of the two lenses E and F permits the chromatic aberrations to be corrected, whereas the difference between the refractive indexes (1.620 and 1.731) of the two lenses permits, due to the curvature of the cemented surface of these two lenses, a correction of the anti-nodes of spherical aberrations;

— a fourth sub-group II*d* having two lenses G and H achieves the correction of spherical aberrations and of a part of the external coma introduced by the lens D; by way of a variation, the lens G, of glass of refractive index 1.62025, could be chromatized with a lens of glass of the same refractive index and of different Abbe number, which will improve the chromatism of the whole.

Next the objective comprises a third group III formed by a single lens J (between the surfaces 16 and 17) which determines the power of the objective, the focal length (23.23 mm) of this lens being slightly smaller than the focal length chosen for the objective (26.7 mm). The lens J is of a glass of high refractive index (1.8). The aberrations that it brings, due to its considerable convergence, are practically all compensated by the lenses of the second group II. By way of a variation, this single jens J could be substituted by two lenses in order to increase the aperture of the overall objective, the group of two lenses also having a focal length slightly smaller than the focal length chosen for the objective.

Finally, the objective comprises a fourth group IV formed by a single divergent lens K (limited by the surfaces 18 and 19), of low refractive index (1.516), placed in the neighbourhood of the image plane Pi of the objective and intended to correct the curvature of the field and the Petzval curvature of the objective.

In the drawing, the paths of a few rays have been shown, including the rays r_1 at F/0.87 and r_2 at F/0.97 when the objective works at infinity, for the wave length 4358 angstroms (*g* line of mercury).

The characteristics of such an objective, constructed by way of a prototype, are given in the following table:

Lens	Surfaces	Thickness in mm.	Radius of curvature in mm.	Refractive index for the *d* line of helium	Abbe number	Diameter of the lens in mm.
	1		785.500			
A		4.00		1.8	V=46	30
	2		−368.850	air		
		0.10				
	3		50.605			
B		5.27		1.72	V=50	30
	4		160.430	air		
		0.065				
	5		32.221			
C		4.82		1.72	V=50	28
	6		68.325	air		
		4.05				
	7		−134.680			
D		2.24		1.73150	V=28	25
	8		108.420	air		
		0.065				
	9		60.033			
E		9.50		1.62025	V=60	23.5
	10		−25.683			
F		2.20		1.73150	V=28	23.5
	11		115.444	air		
		0.065				
	12		68.80			
G		9.48		1.62025	V=60	20
	13		−1235.8	air		
		0.065				
	14		38.907			
H		1.80		1.62025	V=36	16
	15		32.593	air		
		2.51				
	16		20.138			
J		4.70		1.8	V=46	13.2
	17		344.900	air		
		7.05				
	18		13.652			
K		1.50		1.51650	V=64	4.7
	19		55.834			

The objective according to the preceding table, which corresponds to the drawing, has been especially studied for the *g* line of mercury of wave length 4358 angstroms for which the definition is the best (as indicated previously, the average definition of the objective, in a field of 3.5 mm diameter, is 1500 lines/mm for the *g* line of mercury).

The chromatic correction has been made about the *g* line in a manner such that the *F* line of wave length 4047 angstroms is bent back onto the *g* line (4361 angstroms)

g f 0.0040 mm
g h 0.0040 mm

Nevertheless, in view of the aperture of the objective and the desired definition, it is not possible to give the objective an avoidable pass band without reducing the definition.

The characteristics of the objective described above are the following:

focal length:	26.747 mm
extension from the objective to infinity	1.596
magnification:	0.0995
distance from the object to surface 1:	300
distance from the image to surface 19:	1.0665

This reproduction objective has, with respect to reproduction objectives in the prior art, numerous advantages, in particular the following:

First of all, it has an excellent definition.

Its aperture is very large.

The different aberrations are systematically corrected.

It permits printed microcircuits to be manufactured in a very precise manner.

WHAT WE CLAIM IS:—

1. An objective for high definition reproduction, of large aperture and having a given magnification, the objective consisting of the following groups (taken from the object to the image) of lenses; a first group formed by a first single lens of high refractive index, the focal length of which single lens is of the order of ten times the focal length of the objective, said single lens determining the magnification (lower than 1) of the reproduction; a second focal group, having a focal length at least five times greater than that of said first lens for progressively correcting aberrations instroduced by the lens or lenses of the third group; a third group, formed by a second single lens or two lenses, which determines the power of the objective, the focal length of this group being of the same order of size as the focal length of the objective e.g. between 15 mm and 50 mm and the refractive index of the or each lens of the group being greater than 1.75; a fourth group formed by a single divergent lens, having a refractive index of less than 1.55, for correcting the curvature of the field and the Petzval curvature, the power of the single divergent lens being determined by the Petzval correction to be effected.

2. An objective according to claim 1, in which said first single lens is removable from the objective to permit the replacement of the first single lens by a similar lens of different focal length.

3. An objective according to claim 1 or 2, in which the second group is formed by four successive sub-groups, namely: a first group of from one to three lenses, for correcting in part the spherical aberration and the curvature of the field; a second sub-group formed by a single biconcave lens for correcting the spherical aberration and the external coma; a third sub-group having two lenses cemented together and having different Abbe numbers and different indexes of refraction to correct the chromatic aberrations and the anti-nodes of spherical aberrations; a fourth sub-group having two lenses for correcting the spherical aberrations and a part of the external coma.

4. An objective substantially as described hereinbefore with reference to and as illustrated in the accompanying drawings.

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1 SHEET *This drawing is a reproduction o the Original on a reduced scale*